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Assessment of Ocean Optics, Remote Sensing and Numerical Modeling in Europe--1986-87

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The focus of this report is on those institutions which were doing the most significant work in Europe in optical oceanography, remote sensing, and numerical modeling during 1986-87. The work of each of the institutions in its strong area of research is reviewed.

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ASSESSMENT OF OCEAN OPTICS, REMOTE SENSING AND NUMERICAL MODELING IN EUROPE, 1986-87

During calendar years 1986-1987 I visited various marine institutions to discuss their oceanographic programs and, in addition, attended a number of meetings, conferences, and workshops which had ocean science objectives. As a result of this 2-year effort, some pertinent conclusions and assessments were made based on specific observations. It is the purpose of this report to focus on the institutions where the best work is being done and to discuss these observations and the resultant conclusions and assessments.

1 OPTICAL OCEANOGRAPHY

Denmark

Due primarily to the belief that a better knowledge of oceanic optics was required to completely understand remote sensing data, there has been a recent resurgence of interest in the optical properties of the sea and its dissolved and suspended components. Historically, the European leader in this field has been the Oceanography Department of the University of Copenhagen.

At present that department has an active staff of only two people, K. Nygaard and N. Hojerslev. A third member of the department, G. Kullenberg, is on temporary leave, working in Paris for UNESCO. Consequently, activities in Copenhagen are somewhat curtailed.

One of the department's more active optical programs is concerned with *in situ* color measurements for both upwelling and downwelling light. These measurements are designed to measure the spectral characteristics of ambient light, and although many measurements were made at only two colors, 521 and 451 nm, the system is being expanded to include 12 bands. Dr. Hojerslev has been especially active in this area, since he is interested in the color characteristics of scattered light for remote sensing applications. The department has also been very active in using fluorometry over the last 15 years in the measurement of Gelbstoffe (dissolved yellow organic material: yellow stuff) and chlorophyll a, and also in tracking Rhodamine B in various dye studies. The University of Copenhagen people believe that the fluorometric measurements they make relate to a reproducibility of 0.1 mg/m^3 in the measurement of chlorophyll a.

Another of their uses of fluorometry is an attempt to trace the origin of water masses from specific rivers by their fluorometric signature. This project has been going on for some time, but is still incomplete.

The major portion of the Copenhagen laboratory facility is devoted to optical oceanography. The instrument calibration facilities, for example, are probably unique in Europe. There is a large tank (about 3000 gallons) for optical instrument calibration which is fed by a filter system composed of large-capacity millipore filters, so that the water in the tank is kept super clean. There is also a large, clean, magnetically shielded optical calibration room containing optical benches, standard sources and receivers, and other optical devices all maintained in an antiseptic environment. Laboratory facilities are capped off by a small but very well equipped and neat machine shop utilized for the manufacture and development of new optical instruments.

Although the department is active, it is very small, and one gets the impression that the amount of work being attempted by this small department is probably overwhelming. Some of the new computer-oriented developments in data acquisition and storage, common to many of the larger laboratory facilities, have not been incorporated in the Danish effort as yet.

To a visitor the impression is one of a department hanging on by its fingernails with excellent facilities falling into disrepair, graduate students declining in number to almost none, and large numbers of offices and laboratories going unused.

France

In direct contrast to the University of Copenhagen is the marine science laboratory of the Université Pierre et Marie Curie of Paris. It is the major French oceanographic laboratory devoted to scientific studies, including a physical-chemical group, a geophysical group, a biological group, and a very well equipped electronic instrumentation laboratory and workshop. The Laboratoire de Physique et Chimie Marines has a staff of 160 people, including 80 professionals, and is headed by André Morel, who also directs the activities of the physical-chemical group.

Since Morel's major interest lies in the area of optical oceanography the major effort of the physical-chemical group, as might be expected, is in this area. A rather complete image analysis facility has been available to the lab for the last 3 years, and much work in the analysis of coastal zone color scanner (CZCS) and thematic mapper (TM) images has been accomplished in that period. This group has been very successful in the development of atmospheric correction algorithms suitable for use in water types common to European waters, and they intend to continue their efforts with CZCS and TM in addition to attempting their luck with the French SPOT and the Japanese MOS satellites. It appears that coastal area images from both the SPOT and MOS satellites will be amenable to the analysis techniques developed at Villefranche.

Most of the color analysis work has been directed toward the remote determination of either the diffuse attenuation coefficient, k, or chlorophyll concentrations. There is also other work at the laboratory in the area of bio-optics. The optical properties of algal cells, including the measurement of absorption spectra of differing types of phytoplankton, is proceeding. Along with this, a sister study of the thermodynamic characteristics of phytoplankton is underway, including determinations of photosynthesis energetics and specific quantum yields for various species. In support of these activities, there is an elaborate phytoplankton culture facility and a well-equipped laboratory for the study of light scattering.

The UK

In the UK there are two centers of marine optics studies, both on the southwest coast of England. At Plymouth Polytechnic, Derek Pilgrim is accumulating optical data from some of the local estuaries and also trying to develop reasonable mathematical models to adequately describe light attenuation in turbulent waters. At the Institute for Marine Environmental Research (IMER) James Aiken is using the undulating oceanographic recorder, which he developed, to measure suspended particle size and ambient light under various oceanic conditions. The undulating oceanographic recorder consists of a towed vehicle which undulates in a vertical manner so that a vertical section of the upper 100 meters of the water column may be sampled. The device not only has the capability of acquiring water samples for future use, but it also has a number of flow-through sensors that measure various parameters. Since it has been used for about 2 years with a great deal of success, a number of different units have been built. Aiken has taken some of these light measurements and attempted to relate them to the local plankton populations. He has also used these light data to study the relation between color and specific absorption bands of differing kinds of plankton.

The other UK center of study in optical oceanography is at the University of Southampton. Ian Robinson's group at Southampton, as with many other groups attempting to develop means for interpreting color photographs, found itself very quickly involved in optical oceanography. Because the color sensed by the satellite is a result of scattering that occurs within the water column, a knowledge of the optical properties of the water column becomes mandatory. In coastal waters, especially, ground truth must be able to clearly differentiate between inherent and apparent optical properties, and specify them as accurately as possible. Robinson's group is in the process

of developing new instrumentation to attempt to solve, or at least get a better handle, on this problem.

Summary

Good work in marine optics is being done in Europe at the facilities discussed above, but it certainly appears that the Laboratoire de Physique et Chimie Marines at Villefranche in France is the primary European laboratory in this discipline at this time. Resources, people, and motivation all appear to be available in ample supply.

2 REMOTE SENSING

Based on my attendance at many meeting and visiting many institution, my judgment is that the European Ocean color remote sensing community lags behind the American one by a significant amount, especially in the areas of data analysis and application. This may be due to a number of factors, three of which are given here: In the first place, there was a time lag of as much as 5 years between the time CZCS went into orbit and the time the data were readily available in Europe. This allowed American investigators to get a big jump on European users of these data. Second, since this was an entirely new field, there was (and still is) a lack of imaging processing facilities in Europe. (This situation is changing as hardware becomes less expensive, but historically this has been a major reason for the Europeans lagging behind the Americans.) Third, it has been suggested that in the early years, there was a lack of interested people. The European scientific community is small to begin with, and when the new study area of ocean color data analysis came on the horizon, only a very small segment of this population was willing to learn the new technology and begin to use it. It is obvious that in recent years the Europeans are becoming more interested in ocean color as a tool for oceanography--the power of this tool is becoming more and more obvious. The universities are now turning out people who have a knowledge of this tool and will be willing to use it; also, that older, more established investigators are starting to use it. The American lead may disappear in the near future.

The UK

The same comments apply to the field of active remote sensing as the Europeans attempt to ready themselves for the onslaught of data when ERS-1 flies. Research is proceeding at a number of institutions throughout Europe, but in the UK, certainly Southampton University and Dundee University have the most exciting programs.

The leader of the Southampton group is Ian Robinson, whose background is in estuarine dynamics, but who is becoming more and more involved with remote sensing. Since his beginning in this area about 5 years ago, he has become a national figure and serves on a number of national and international committees and policy groups. One of his current projects involves the analysis of CZCS scenes of the UK shelf seas. He is looking at the areas where fronts appear to exist for a goodly portion of the year--near the Isle of Wight in particular--using imaging processing equipment available at the university. Various problems have arisen, one being that some of the analysis algorithms will tend to suppress the large horizontal gradients normally associated with frontal regions. There is also a calibration problem since the procedures designed for open oceanic areas do not work too well in these coastal waters. However, Dr. Robinson believes he is acquiring new insights into the dynamic relationships between the coastal water masses that exist in this highly energetic environment.

Another project being pursued by Robinson and his students is one in which an attempt is being make to correlate IR and color data from the same area in an effort to study eddies. As is well known, temperature and color sensors respond to different kinds of excitation, and the major objective of this study is to see where the response similarities and differences lie. Calibration of ground truth instrumentation is proceeding where the

instruments exist, but due to the non-availability of certain pieces of gear to make specific color measurements, development of new devices or modification of existing ones is necessary. This study is also concerned with developing new atmospheric correction algorithms, because atmospheric anomalies produce large effects when IR and color data are used.

Robinson is also involved with synthetic aperture radar (SAR) measurements, since one of his students who is taking part in the Gibraltar Experiment will be processing some data from this experiment. This requires some knowledge of the ocean's surface configuration, especially with regard to the small capillary waves that do most of the radar energy scattering. Robinson believes that the key to understanding the SAR return is a better understanding of these capillaries, and he is certainly not unique in this feeling. He is attempting to develop laboratory techniques using a slice of light to illuminate the water surface while setting a camera at some grazing angle to the surface in order to get a profile photograph of the water surface. Enough photographs have been obtained to encourage him to continue to develop this technique for the study of capillaries under various conditions.

The Physics Department at the University of Dundee has been involved in image analysis of oceanic and atmospheric remote sensing data for almost 20 years, and is the acknowledged leader in this field among British universities. Just recently a reorganization has placed physics in a renamed Department of Applied Physics and Electronic and Manufactured Engineering (DAPEME), which may make the remote sensing activity even more efficient. The kingpin of this effort at Dundee is Professor A.P. Cracknell, one of only six staff members in the department directly engaged in remote sensing activities. These activities include image processing software development, atmospheric correction algorithm development, and data processing and interpretation. Data are obtained from multispectral and pushboom scanners, both from unmanned satellites and manned aircraft, as well as large-format cameras, such as flown on Shuttle missions. The objectives of this program are to first obtain a greater understanding of the nature of the reflection and emission processes at the surface of the earth and the transmission of electromagnetic radiation through the atmosphere. The second objective is to utilize this greater understanding in the extraction of geophysical parameters from the data. These data are being used in the following applications:

- Description of marine geophysical processes
- Coastal erosion, coastal mapping, and bathymetry
- Pollution monitoring
- Sea-surface temperature
- Oceanic fronts and eddies
- Development and use of image processing software.

The remote sensing group at the University of Dundee has followed an independent and innovative research path ever since its formation almost 20 years ago, and continues to do so today. Being acknowledged leaders in the field the university has attracted graduate students, and at the present time there are about 10 students pursuing advanced programs in remote sensing. Although the research activities within DAPEME are of high quality by anyone's standards, Dundee's major contribution to British science might very well be the continuing production of a significant number of scientists who are not only aware of the power and limitations of remote sensing techniques, but are also adept at using them to maximum advantage. In addition to the more traditional training of remote sensing specialities, the department is able to offer summer courses of a more general nature to give environmental science workers a broad foundation in those areas of the field which have particular interest.

Italy

Tucked away in the Istituto di Gasdinamica, Facolta di Ingegneria at the

Universita Degli Studi di Napoli, is a small remote sensing group of seven professionals headed by Professor Sergio Vetrella. One of the first software projects undertaken by the newly formed group in 1968 was the simulation of the geometric errors common to all satellite images. The resulting program has been highly successful and is used as a package in just about all projects tackled by the group. Other characteristics being simulated include orbit parameters, sensor attitude, location determination precision, geographic coordinate relationships, and atmospheric refractive effects. This latter parameter is particularly important when dealing with high-resolution sensors, and present models allow the use of standard atmospheric profiles or actual data or any combination of the two. A rather detailed analysis has been accomplished for the high-resolution pushbroom sensor, such as used on SPOT, with particular attention to the degradation of high-frequency data resulting from dynamic morphology. Other special problem areas associated with SPOT, such as the translation of altitude and nadir angle errors to inaccuracies in horizontal location and local elevation are also being considered.

Active microwave sensors such as SAR are also under study, reflecting the strong interest of the oceanic remote sensing community. A simulation of the X-band SAR to be used on the next shuttle mission includes data from fixed corner reflectors serving as image intensity standards as well as points of known location. Another SAR project, called Maestro, is being accomplished in conjunction with NASA. Here, C- and L-band radars are being used with the Naples University X-band gear in a program designed to calibrate water surface configurations and relate the different radar types by setting corner reflectors on a conveniently located lake.

Another capability of more than passing interest is the group's capacity for simulating various target characteristics. Backscattering properties of any geometric shape (or any linear combination of any two or more shapes) allow the determination of the relationships between SAR signals of any frequency and simple-shape topographic features. A special SAR processor has been developed that digitizes analog data and allows the use of data from aircraft, shuttle, and satellite platforms.

France

Oceanographic remote sensing activities at the Ministry of Research (MRES) in Paris are headed by Joseph Gonella, the coordinator of French remote sensing efforts. As might be expected, the French are very interested in maximum use of the SPOT satellite, so MRES has an active program to explore novel techniques of extracting applications-oriented information from SPOT images. This program, called Programmed Exploitoire et Propetoire SPOT (PEPS), is being pursued by groups at IFREMER and the University of Marseilles.

One idea being examined is the possible use of sun-glint photos, since these pictures may contain information similar to that in SAR images. SPOT is particularly well suited to obtain this type of scene because it is possible to vary both the sensor nadir and azimuth angles by appropriate ground commands. The panchromatic sensor is used, and it is pointed toward the east in the morning. These images have not only been used to study internal waves and eddies in the region of Gibraltar, but they are also being used in the intertidal zone to help in management of oyster fisheries. Work is also being done to directly relate "sea truth" to satellite measurements.

There is some activity by MRES in the area of active sensors as well. A group at the French Meteorological Office interested in scatterometer applications is operating with the TOPEX group in Toulouse in an attempt to enhance both scatterometer and altimeter data by coordination and concurrent use. The possibility of using active sensors in helping to solve beach erosion problems is being addressed by a number of groups working together. These include a modeling group at on branch of the University of Paris,

and other modeling, data assimilation, and data validation groups at Toulouse. In addition, at another branch of the University of Paris some basic research involving the physics of radar backscattering is being pursued.

France's Institut de Mécanique Statistique de la Turbulence (IMST) of the Université d'aix-Marseille has a separate laboratory located at the Luminy campus of the university devoted primarily to the study of the air/sea interface. The director of the lab is A. Ramamonjiarisoa, and he has a staff of 19 professional people plus support personnel who operate and maintain the two major air/sea interaction research tools located at this installation. These are two very similarly designed water channels, each having the capability of wave and current production in the water channel, while at the same time a variable air stream is located just above the water surface so that wind-generated waves may also be produced.

The effect of different sea-surface configurations on scattered electromagnetic signals is also being studied. A radar scatterometer simulator has been mounted above the larger test flume so that basic relationships between sea-surface configuration and scattered EM signal can be ascertained. Different wind speeds, plus independent conditions produced by currents and separately generated waves, along with any synergistic effects, can be examined. These data, along with any relationships that result, should be invaluable when it comes time to interpret scatterometer data from the ERS-1 satellite. At the same time, though, a much better understanding of the basic physical processes involved in the operation of the scatterometer should be acquired. Attempts are also being made to identify the portion of the waves actually doing the backscattering, and in the process, develop some sort of a consistent scattering theory.

The Netherlands

In the Netherlands Dr. Daniel Spitzer is head of the newly created section on remote sensing within the Tidal Waters Division of the Ministry of Transport and Public Works. The objective of this section is to determine the remote sensing technique that can best be applied to the assigned tasks of the division. Initially they will be working in three specific areas which include:

- The use of current-measuring radar, primarily for sediment transport studies
- Use of electromagnetic bathymetry systems, including both microwave (synthetic aperture and side-looking airborne radars) and laser techniques, not only to measure water depth but also to obtain information about the optical properties of the water column
- The development of improved methodologies to enhance interpretative skills in the analysis of passive sensor data from systems such as the TM.

At the present time the group appears to be concentrating on the effective use of data obtained from sensors on aircraft. In particular, they are attempting to develop algorithms that will improve the utility of both microwave and laser instruments and allow for the extraction of bottom information from multispectral data.

Sweden

Also actively involved in remote sensing research is a group at the Chalmers University of Technology in Gothenburg, Sweden. The remote sensing group there was formed in 1984 within the Department of Radio and Space Science when a professorship in this discipline was created. Professor Jan Askne is the present and original holder of this chair at Chalmers.

The activities of the remote sensing group are almost exclusively in the areas of meteorology and oceanography, with strong emphasis on the sensing of atmospheric properties, both in terms of inherent atmospheric characteristics and the effect of the atmosphere on oceanographic remote sensing. The group is also concerned with remote sensing of sea ice (using both radar altimetry and synthetic

aperture radar) and oil spills (using microwave radiometry).

Summary

European activities in remote sensing are improving in both quantity and quality, but resource problems continue. The following comments can be made:

1. The European remote sensing community is very small. Although many of the people are high-quality investigators, progress will continue to be slow unless more young researchers are attracted into the community.
2. The effort in Europe to commercialize remote sensing has occurred before a significant basic research program has been able to produce many of the tools required to effectively use remote sensing data. Consequently, the number of economically feasible commercial uses of remote sensing data that have been successfully demonstrated is minimal.
3. It is hard to judge how much cooperation really exists between the various member laboratories of the European community. There seems to be little evidence of any joint laboratory projects, for example.
4. Americans appear to dominate the field, but this may change when ERS-1 starts producing data in the early 1990's.

3 NUMERICAL MODELING

European Universities have always had a reputation for excellence in mathematically related studies. With the increasing use of numerical modeling techniques, both in forecasting and in basic studies, institutions with strong mathematical departments have found it easy to become involved in studies of this type. Unfortunately, many environmental models require computers of the CRAY class, so that modeling work in Europe tends to be limited by the size of computer available.

The UK

Among the premier groups in the UK is the Hooke Institute for Atmospheric Research which was founded by a small group of people who moved to Oxford in 1984 from the Department of Applied Mathematics and Theoretical Physics at Cambridge University. The group is funded from three separate sources: The Atmospheric Research Department of Oxford University (one staff member), The UK Meteorological Office (three staff members), and the National Environmental Research Council (one staff member). The institute also receives a small grant form the US Office of Naval Research to help with the publication and distribution of the informal journal entitled *Ocean Modeling*.

The institute's major, if not sole, activity is in the general area of atmospheric and oceanic circulation modeling. Hooke Institute researchers continue to be active in the development of circulation models of the equatorial ocean (as part of the TOGA project), the Norwegian and Greenland Seas, the North Atlantic Ocean, and the Antarctic Ocean and Weddell Sea. Their plans apparently are to increase their activities by attempting to use satellite data in some of the modeling efforts. In particular, they are using simulated satellite altimeter data to obtain sea-surface slope values to examine the possibility of using this type of data in future numerical models. There is also a group from the Meteorological Office involved in satellite image interpretation.

Another UK University with a heavy modeling effort is East Anglia University where both El Nino and ice formation models are being pursued. Smaller groups at Imperial College, Salford University, and Exeter University are considering problems associated with eddy resolving models, diffusion models, and long wave models. In addition, a larger group at Southampton University is addressing circulation and tropical models, along with another group at the University College of North Wales which is more interested in coastal and estuarine models.

The UK research institutions are also heavily into modeling with a new community project (multi-institutional) called FRAM (Fine Resolution Antarctic Model) being mounted in association with

the university community. The Deacon Oceanographic Laboratory is the lead laboratory for this project, and DOL personnel are also involved in modeling related to the World Ocean Circulation Experiment (WOCE), internal tidal mixing, and general circulation, along with studies regarding the assimilation of altitude data into circulation models. The Meteorological Office is directing a lot of attention toward coupled air-atmosphere circulation models, especially aimed at the El Nino problem. Other UK modelers include R. Uncles of IMER, who specializes in estuarine circulation models, and R. Pingree of MBA, who has developed a very highly regarded tidal prediction model.

France

In France, the group at Villefranche includes about 10 people involved in large-scale dynamics under the leadership of C. Frankignoul and in mesoscale circulation studies led by L. Prieur. They are looking at oceanic variations on scales of months to decades, with particular attention bring directed at the air/sea interaction problem, with emphasis on feedback effects in the tropical ocean. The El Nino phenomenon is being addressed as attempts are being made in conjunction with some people at NASA to fit temperature data into general circulation models. The mesoscale effort is centered in the Mediterranean with attempts being made to assimilate SEASAT altimeter data into locally developed circulation models. There is also a strong interest in frontal dynamics, as both frontal genesis and frontal profiles are being investigated. Residence times for various parts of the Mediterranean are also being examined.

The Netherlands

The Delft Hydraulics Laboratory in the Netherlands is heavily involved in the development of mathematical models to support mixing, sediment transport, and pollution studies, and has a large battery of computers (CRAY-1, Cyber 205, and several lesser VAX, Sperry,and IBM units) available for their use. Dr. Herman Gerritsen of the division's coastal seas oceanography group filled me in on some of the ongoing work in storm surge modeling of the northwestern European continental shelf. The model has a grid size of 3×5 nautical miles and has been used primarily for ship routing, but it has recently been extended for use in modeling the subgrid tidal circulation. So far the investigators have found a strong dependence on bottom topography and a marked disparity between vorticities determined at the small grid scale and those associated with larger grid sizes.

Another modeling project is concerned with fronts in the North Sea. They are using a combination of thermal and haline stratification in an effort to develop a model that can be used for pollution dispersion prediction. An integral part of the effort involves the development of methods to facilitate the assimilation of satellite data, especially IR data, into their models. In this effort they are being funded by the European Space Agency (ESA) as part of the ERS-1 verification program.

Norway

Norway also supports a modeling effort, with the University of Oslo's Mechanics Department being a good example. Four or five graduate students are working on numerical modeling problems. One of the models being developed is of the Norwegian coast; it consists of a coarse, general circulation model with a nested finer mesh model. They are also doing some work on the analysis of side-looking radar (SLAR) data taken from Norwegian aircraft over the North Sea when internal waves were present. There is still another group in the Mechanics Department analyzing surface wave data from Norwegian Shelf oil rigs. Other projects include:

- Modeling of surface wave mass transport
- Atmospheric coupling of this transport
- Ice/ocean dynamics
- Storm surge problems.

The Geophysical Institute of the University of Bergen is divided into

departments of meteorology, oceanography, and solid earth. Two of the people in this institute, Hernan Gade and Harald Svendsen, are both working on the dynamics of fjords and estuaries. Gade has developed a working numerical model of fjord circulation for the Norde Fjord in conjunction with Anton Edwards, from the Scottish Marine Biological Association. Gade, Svendsen, and Edwards are attempting to develop a model capable of resolving layers on the order of 10 cm thick, and are going through an intense measurement effort in support of their model. The model includes runoff and wind stress, and within the not too distant future will be refined from its present two-layer configuration to a three-layer form.

West Germany

Perhaps the best wave modeling work being done in Europe is that by A. Hasselman and his group at the Max Planck Institut für Meteorologie in West Germany. The SWAMP and WAM models that resulted with his direction are respected worldwide and are presently in the process of being installed at the European Mid-Range Forecasting Center in the UK.

Summary

In general, the work in numerical modeling being done in Europe is of good quality, but it seems to be limited in quantity by the lack of generally available large-scale computers. Every conference devoted to modeling is dominated by Americans, and there does not seem to be any major change in this situation that will occur in the near future. One example of this American presence is the oceanographic work presently being done in the Mediterranean. The major portion of the effort is being coordinated and probably funded to a large extent by the US. All three of the major projects--POEM, WMCE, and the Gibraltar experiment--certainly fall into this category. Work of good scientific quality is generally associated with these three experiments. The work outside the confines of these three experiments is generally of lesser quality.